## First a Quick Review on Three-Phase Circuits :

| **Star ( wye )** $Y$ | **Delta** $\Delta$ |
| --- | --- |
| $I_p = I_l$<br>$V_p = V_l/\sqrt{3}$<br>$P = \sqrt{3}V_l I_l \cos\theta_p$ | $I_p = I_l/\sqrt{3}$<br>$V_p = V_l$<br>$P = \sqrt{3}V_l I_l \cos\theta_p$ |
| $Z_{\text{wye}} = \frac{1}{3}Z_{\text{delta}}$ | |
| $\text{VA} = \sqrt{3}V_l I_l$<br>$Q = \sqrt{3}V_l I_l \sin\theta_p$<br>$\tan\theta_p = \frac{Q}{P}$ | |

## The Simple Power System Components

$$Generation \Rightarrow Transmision \Rightarrow Distribution$$

Transmission Line (T.L.) can be done in two ways

| Cables | T.L |
| --- | --- |
| High cost | Less cost |
| Hard maintenance | Less hard maintenance |
| Less faults | More faults |

Transmission Line components :
R ( Heat effect) , L ( Magnetic Effect ), C ( Electric Effect)
can be a single-phase or three-phase T.L.
or concentrated or stranded ( composed )

شوية نظري :

## Skin Effect :

In **DC :** the current is uniformly distributed over the cross section of the conductor

But in **AC :** the current is not uniformly distributed over the cross section of the conductor and this increases with higher frequencies so $R_{AC} > R_{DC} \Rightarrow \quad R_{AC} = 1.15\, R_{DC}$

## Voltage Regulation :

The ration between the no load voltage and the full load voltage   and the full load voltage $\frac{V_{n.l} - V_{f.l}}{V_{f.l}}$

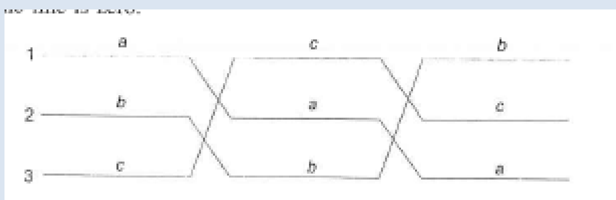
## Corona

Conductor ظاهرة تأين الهواء المحيط بال

Transposition ويتم حلها عن طريق ال

## Transposition

It's a technique performed to the case of unequally spaced phases to have a nearly the same inductance per phase that by changing the position of the phase as shown in the fig.




## Transmission line cables

a)copper "high cost"       b)aluminum alloys with steel

types of conductors :

**AAC:** all-aluminum conductor

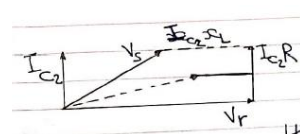
**AAAC:** All-Aluminum alloy conductor

**ACSR:** Aluminum conductor steel reinforced

**ACAR:** Aluminum conductor alloy reinforced

## Ferranti Effect

It's the effect at receiving ( no load / light load ) then the $V_r > V_s$ , and fixed by putting Inductors at the receiving End



# RESISTANCE :

$$R = \frac{\rho L}{A}$$

# INDUCTENCE :

Cables : A) concentrated B) stranded

## A) Concentrated

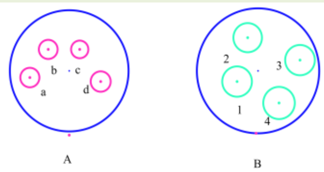
$$L = 2 * 10^{-7} \ln\left(\frac{D}{r'}\right) \quad \Rightarrow \frac{H}{m}$$

$$L_{total} = 2 * 10^{-7} \ln\left(\frac{D}{r'}\right) \times Length \; = \qquad H$$

$$where\; r' = \; 0.7788\, r$$

## B) Stranded (Composed )

**$Single - Phase\ system\ (1 - \phi)$**




A has m lines in it

B has n lines in it

$$L_A \; = 2 * 10^{-7} \ln\left(\frac{GMR}{GMD}\right) \; = 2 * 10^{-7} \ln\left(\frac{Dm}{D_{SA}}\right)$$

$$L_B \; = 2 * 10^{-7} \ln\left(\frac{Dm}{D_{SB}}\right)$$

$$D_m \; = \sqrt[m \times n]{(D_{a1}D_{a2} \ldots D_{an}\,)(D_{b1}D_{b2} \ldots D_{bn}) \ldots (D_{z1}D_{z2} \ldots D_{zn})}$$

$$D_{SA} \; = \sqrt[m^2]{(D_{aa}D_{ab}D_{ac} \ldots D_{az})(D_{ba}D_{bb}D_{bc} \ldots D_{bz}) \ldots (D_{za}D_{zb}D_{zc} \ldots D_{zz})}$$

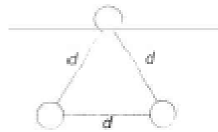
$$where\;\; D_{aa} = 0.7788\, r_a \quad the\ same \; = D_{bb} = D_{cc}$$

$$D_{SB} \; = \sqrt[n^2]{(D_{11}D_{12}D_{13} \ldots D_{1n})(D_{21}D_{22}D_{23} \ldots D_{2n}) \ldots (D_{n1}D_{n2}D_{n3} \ldots D_{nn})}$$

$$where\;\; D_{11} = 0.7788\, r_1 \quad the\ same \; = D_{22} = D_{33}$$

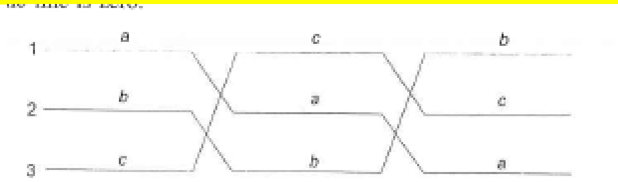
## $\boldsymbol{Three - Phase\ system\ (3-\phi)}$

### 1) Equally spaced




$$L_a = L_b = L_c = 2 * 10^{-7} \ln\left(\frac{D}{r'}\right)$$

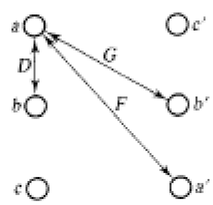
### 2) Not Equally spaces




$$L_a = 2 * 10^{-7} \ln\left(\frac{D_m}{r'}\right)$$

$$D_m = \sqrt[3]{D_{ab} D_{bc} D_{ac}}$$

### **3) Double** Circuit




ميزاته 1- يقلل ال corona 2- حتى اذا حدث خطأ في الكهربا لخط الخط التاني يعمل كباك اب

$$L_A = 2 * 10^{-7} \ln\left(\frac{D_m}{D_s}\right)$$

| | |
|---|---|
| $D_m = \sqrt[3]{D_{AB} D_{BC} D_{CA}}$<br>$D_{AB} = \sqrt[4]{D_{ab} D_{ab'} D_{a'b} D_{a'b'}}$<br>$D_{BC} = \sqrt[4]{D_{bc} D_{bc'} D_{b'c} D_{b'c'}}$<br>$D_{CA} = \sqrt[4]{D_{ca} D_{c'a} D_{ca'} D_{c'a'}}$ | $D_s = \sqrt[3]{D_{AA} D_{BB} D_{CC}}$<br>$D_{AA} = \sqrt[4]{D_{aa} D_{a'a} D_{aa'} D_{a'a'}}$<br>$D_{BB} = \sqrt[4]{D_{bb} D_{b'b} D_{bb'} D_{b'b'}}$<br>$D_{CC} = \sqrt[4]{D_{cc} D_{c'c} D_{cc'} D_{c'c'}}$<br>$where:\ D_{a'a'} = D_{aa} = 0.7788\, r_a$<br>وهكذا مع باقي الخطوط b و c |

4) Bundle

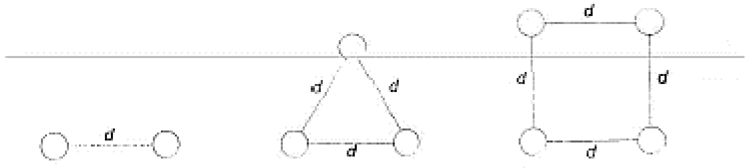



Fig. 2.16 Configuration of bundled conductors

# Capacitance :

## $single-phase\ T.L.\ Capacitance\ (1-\phi)$

$$C_{LG}=\frac{2\pi\epsilon_0}{ln\left(\frac{D}{r}\right)}\quad F/m$$

$$C_{LL}=\frac{\pi\epsilon_0}{ln\left(\frac{D}{r}\right)}$$

$$\epsilon_0\ =8.85*10^{-12}$$

## $Three-phase\ T.L.\ Capacitance\ (3-\phi)$

### 1) Equally spaced

$$C_{ph}=\frac{2\pi\epsilon_0}{ln\left(\frac{D}{r}\right)}\quad F/m/ph$$

### 2) Not equally spaced

$$C_{ph}=\frac{2\pi\epsilon_0}{ln\left(\frac{D_m}{r}\right)}$$

$$D_m=\sqrt[3]{D_{ab}D_{bc}D_{ca}}$$

### 3) Double Circuit

$$C_{AN}\ =C_{an}+C_{a'n}$$

$$C_{an}=C_{a'n}\ =\frac{2\pi\epsilon_0}{ln\left(\frac{Dm}{D_s}\right)}$$

$$\therefore C_{AN}=\frac{4\pi\epsilon_0}{ln\left(\frac{Dm}{D_s}\right)}$$

| | |
|---|---|
| $D_m = \sqrt[3]{D_{AB}D_{BC}D_{CA}}$<br>$D_{AB} = \sqrt[4]{D_{ab}D_{ab'}D_{a'b}D_{a'b'}}$<br>$D_{BC} = \sqrt[4]{D_{bc}D_{bc'}D_{b'c}D_{b'c'}}$<br>$D_{CA} = \sqrt[4]{D_{ca}D_{c'a}D_{ca'}D_{c'a'}}$ | $D_s = \sqrt[3]{D_{AA}D_{BB}D_{CC}}$<br>$D_{AA} = \sqrt[4]{D_{aa}D_{a'a}D_{aa'}D_{a'a'}}$<br>$D_{BB} = \sqrt[4]{D_{bb}\,D_{b'b}D_{bb'}D_{b'b'}}$<br>$D_{CC} = \sqrt[4]{D_{cc}D_{c'c}D_{cc'}D_{c'c'}}$ |

## Charging current

$$(\boldsymbol{I_{ch}})\text{"}\boldsymbol{Charging\ Current}\text{"} = \frac{\boldsymbol{V_\phi}}{\boldsymbol{-jx_c}} = \qquad \angle\boldsymbol{90}$$

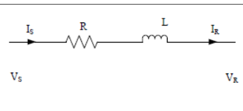
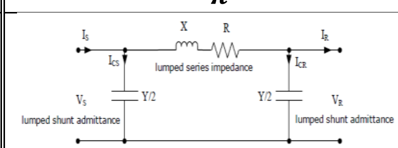
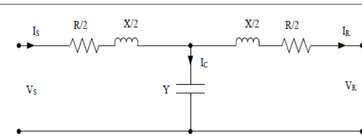
$$|\boldsymbol{I_{ch}}| = \frac{\boldsymbol{V}}{\boldsymbol{X_c}} = \frac{\boldsymbol{V_{ph}}}{\frac{\boldsymbol{1}}{\boldsymbol{\omega c}}} = \frac{\boldsymbol{V_{ph}}}{\frac{\boldsymbol{1}}{\boldsymbol{2\pi f\ c}}} = \boldsymbol{2\pi f c\, V_{ph}} = \boldsymbol{2\pi f c}\frac{\boldsymbol{V_l}}{\boldsymbol{\sqrt{3}}}$$

## Performance of short T.L

$$efficiency = \eta = \frac{P_{out}}{P_{in}} = \frac{P_r}{P_s}$$

$$Regulation = \%Reg = \frac{\Delta V}{V_r} = \frac{\frac{|V_s|}{A} - |V_r|}{|V_r|} * 100 = \frac{|V_{n.l}| - |V_{f.l}|}{|V_{f.l}|} * 100$$

## *Types of Transmission Lines*

| SHORT T.L | MEDIUM T.L | | LONG T.L |
|---|---|---|---|
| L<80 km | 80 < L <250 | | 250 < L |
| | **π** | **T** | |
|  |  |  | |
| $\boldsymbol{A} = \boldsymbol{D} = 1$<br>$\boldsymbol{B} = Z$<br>$\boldsymbol{C} = 0$ | $\boldsymbol{A} = \boldsymbol{D} = 1 + \frac{ZY}{2}$<br>$\boldsymbol{B} = Z$<br>$\boldsymbol{C} = Y\left(1 + \frac{ZY}{4}\right)$ | $\boldsymbol{A} = \boldsymbol{D} = 1 + \frac{ZY}{2}$<br>$\boldsymbol{B} = Z\left(1 + \frac{ZY}{4}\right)$<br>$\boldsymbol{C} = Y$ | $\boldsymbol{A} = \boldsymbol{D} = cosh\theta = \left(1 + \frac{ZY}{2}\right)$<br>$\boldsymbol{B} = \frac{zsinh\theta}{\theta} = Z\left(1 + \frac{ZY}{6}\right)$<br>$\boldsymbol{C} = \frac{Ysinh\theta}{\theta} = Y\left(1 + \frac{ZY}{6}\right)$ |

$$V_s = A\,V_r + B\,I_r$$
$$I_s = D\,V_r + C\,I_r$$

**قوانين مهمه لحل مسائل ال T.L**

$$short\ V_s = V_r + i(\ R + jX_l)$$

$$P_S = |V_S||I_S|\ PF_s \quad ; PF_S = \cos(\widehat{V_s} - \widehat{\iota_s})$$

$V_\phi = \frac{V_L}{\sqrt{3}}$ الجهد اللي بيدهولك دايما جهد لاين

$$P_\phi = \frac{P_{3\phi}}{\sqrt{3}}$$

$$S = P + jQ$$

$$\therefore P = PF * S$$

$$S = \dot{I}\ V \cos(\hat{V} - \hat{I})$$

$$I_{1\phi} = conj\left[\frac{S_{3\phi}}{3 * V}\angle(\pm \cos^{-1} PF)\right] = conj[\frac{P_{3\phi}}{3 * PF * V}\angle(\pm \cos^{-1} PF)]$$

$$Y = \frac{1}{X_C} = 2\pi f C$$

لما تلاقيه بيطلب جهود كتير طبق كيرشوف للجهود على رسمه ال T.L

لما متعرفش تحل المسأله (زي مساله الميدتيرم )ارسم ال phasor diagramو حاول تستنتج منه الحل وشويه علاقات تلم بيهم أي درجه

Double circuit means Rt=Rcir/2 Lt=Lcir/2 Yt=Ycir*2

By:Mohamed Numair

## T.L Design

### Electrical Considerations for T.L. Design

- **Low voltage drop**
- **Minimum power loss for high efficiency of power transmission.**
- **The line should have sufficient current carrying capacity so that the power can be transmitted without excessive voltage drop or overheating.**

### Mechanical Considerations for T.L. Design:

**• The conductors and line supports should have sufficient mechanical strength:**

**- to withstand conductor weight,Conductor Tension and weather conditions (wind, ice).**

**- The Spans between the towers can be long.**

- **Sag will be small.**
- **Reducing the number and height**

## Main components of Overhead lines:

1) Conductors
2) Supports
3) Insulators
4) Cross arms
5) Other items such as lightning arrestors.

## Line Supports Properties:

1) High mechanical strength to withstand weight of conductor
2) Light in weight
3) Cheap in cost
4) Longer life
5) Easy accessibility of conductor for maintenance

## Types of Line Supports:-

Wooden poles

Steel poles

Reinforced Concrete Poles (RCC)

Lattice steel towers

| Wooden poles | Steel Poles |
|---|---|
| Shorter span up to 50 m | Greater mechanical strength•<br>Longer life•<br>Larger spans•<br>Used for distribution purpose in cities•<br>Three types: Rail poles Tubular •<br>poles |

| | |
|---|---|
| Less cost & used for distribution purpose in rural<br><br>areas<br><br>Pesticides required e.g creosote oil<br>Used for voltage up to 20 kv<br>Smaller life(20-25 years)<br>Less mechanical strength<br>Made of Sal or Chir<br>Moderate cross-sectional area | Rolled steel joints |
| RCC(Reinforced concrete poles):- | Steel towers :- |
| • Greater mechanical strength<br>•Longer life<br>•Longer spans<br>•Good outlook<br>•Little maintenance<br>•Good insulating properties Two Types:-<br>-Single pole -Double poles | Longer life •<br>Longer span•<br>Greater mechanical strength•<br>For long distance at high voltage•<br>Tower footings are usually grounded by driving •<br>rods into the earth .This minimizes lightning<br>troubles as each tower acts as lightning<br>.conductor |

## Types of Towers

1- Suspension Tower

2- Tension Tower

3- Angle Tower

4- End Tower ( Beginning and end of the line one side tension)

## Insulators

## Properties of Insulating Material

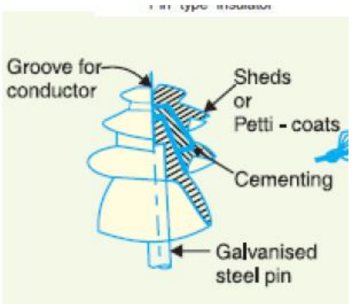
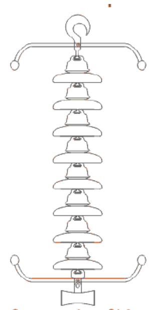
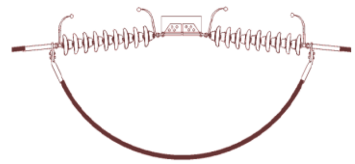
The materials generally used for insulating purpose is called **insulating material**. For successful utilization, this material should have some specific properties as:-

- It must be mechanically strong enough to carry tension and weight of conductors.
- It must have very high dielectric strength to withstand the voltage stresses in High Voltage system. (high relative permittivity).
- It must possesses high Insulation Resistance
- to prevent leakage current to the earth.
- The **insulating material** must be free from unwanted impurities.
- It should not be porous.
- There must not be any entrance on the surface of electrical insulator so that the moisture or gases can enter in it
- There physical as well as electrical properties must be less effected by changing temperature.

## Types of Insulators

1) Pin Insulators
2) Suspension Insulators
3) Strain Insulators
4) Stay and shackle in low voltage applications

| Pin Insulators | Suspension Insulators | Strain Insulators |
|---|---|---|
| Pin Insulator is earliest developed overhead insulator, but still popularly used in power network up to 33 KV system.<br>Pin type insulator can be one part, two parts or three parts type, depending upon application voltage.<br>In 11 KV system we generally use one part type insulator where whole pin insulator is | In higher voltage, beyond 33KV, it becomes uneconomical to use pin insulator because size, weight of the insulator become more. Handling and replacing bigger size single unit insulator are quite difficult task. For overcoming these | When suspension string is used to sustain extraordinary tensile load of conductor it is referred as **string insulator**. When there is a dead end or there is a sharp corner in transmission line, the line has to sustain a great tensile load of conductor or strain. A **strain insulator** must have |

| | | |
|---|---|---|
| one piece of properly shaped porcelain or glass.<br><br> | difficulties, suspension insulator was developed.<br><br>In **suspension insulator** numbers of insulators are connected in series to form a string and the line conductor is carried by the bottom most insulator. Each insulator of a suspension string is called disc insulator because of their disc like shape.<br><br>Suspension String | considerable mechanical strength as well as the necessary electrical insulating properties<br><br>STRAIN INSULATOR |

| Rated System Voltage | Number of disc insulator used in strain type tension insulator string | Number of disc insulator used in suspension insulator string |
|---|---|---|
| 33KV | 3 | 3 |
| 66KV | 5 | 4 |
| 132KV | 9 | 8 |
| 220KV | 15 | 14 |

## Advantages of Suspension Insulator

1. Each suspension disc is designed for normal voltage rating 11KV (Higher voltage rating 15KV), so by using different numbers of discs, a suspension string can be made suitable for any voltage level.

2. If any one of the disc insulators in a suspension string is damaged, it can be replaced much easily.

3. Mechanical stresses on the suspension insulator is less since the line hanged on a flexible suspension string.

4. As the current carrying conductors are suspended from supporting structure by suspension string,

the height of the conductor position is always less than the total height of the supporting structure. Therefore, the conductors may be safe from lightening.

**Disadvantages of Suspension Insulator**

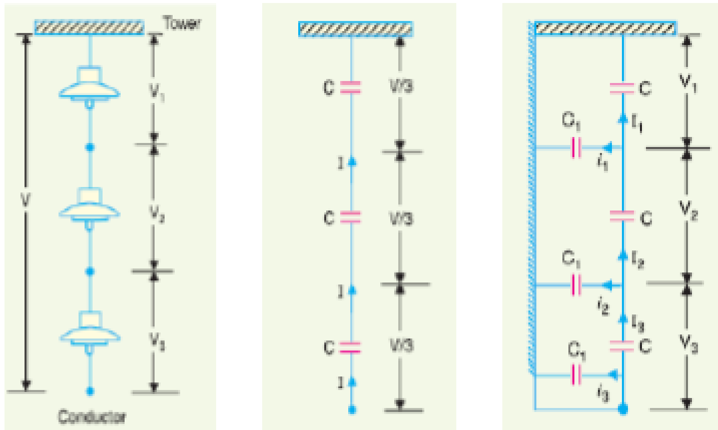
1. Suspension insulator string costlier than pin and post type insulator.

2. Suspension string requires more height of supporting structure than that for pin or post insulator to maintain same ground clearance of current conductor.

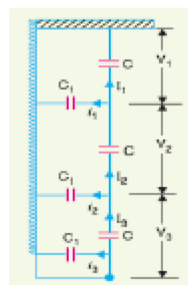
3. The amplitude of free swing of conductors is larger in suspension insulator system, hence, more spacing between conductors should be provided.

Potential Distribution over suspension insulator string

## Potential distribution over suspension insulator string




## Potential distribution over suspension insulator string



The following points may be noted regarding the potential distribution over a string of suspension insulators :

(*i*) The voltage impressed on a string of suspension insulators does not distribute itself uniformly across the individual discs due to the presence of shunt capacitance.

(*ii*) The disc nearest to the conductor has maximum voltage across it. As we move towards the cross-arm, the voltage across each disc goes on decreasing.

(*iii*) The unit nearest to the conductor is under maximum electrical stress and is likely to be punctured. Therefore, means must be provided to equalise the potential across each unit. This is fully discussed in Art. 8.8.

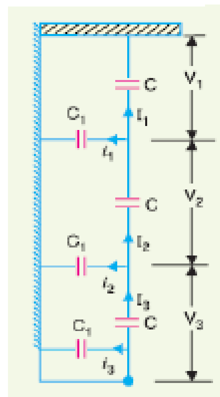
(*iv*) If the voltage impressed across the string were d.c., then voltage across each unit would be the same. It is because insulator capacitances are ineffective for d.c.

# String Efficiency

*The ratio of voltage across the whole string to the product of number of discs and the voltage across the disc nearest to the conductor is known as* **string efficiency** *i.e.,*

$$\text{String efficiency} = \frac{\text{Voltage across the string}}{n \times \text{Voltage across disc nearest to conductor}}$$

where $\quad n$ = number of discs in the string.




Applying Kirchhoff's current law to node $A$, we get,

$$I_2 = I_1 + i_1$$

or $\quad V_2 \omega C^* = V_1 \omega C + V_1 \omega C_1$

or $\quad V_2 \omega C = V_1 \omega C + V_1 \omega K C$

$\therefore \quad V_2 = V_1 (1 + K) \qquad \ldots(i)$

Applying Kirchhoff's current law to node $B$, we get,

$$I_3 = I_2 + i_2$$

or $\quad V_3 \omega C = V_2 \omega C + (V_1 + V_2) \omega C_1 \dagger$

or $\quad V_3 \omega C = V_2 \omega C + (V_1 + V_2) \omega K C$

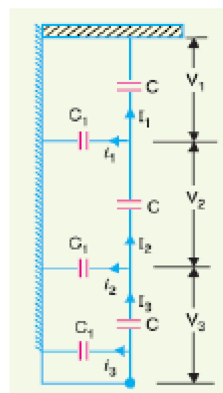
or $\quad V_3 = V_2 + (V_1 + V_2)K$

$$= KV_1 + V_2 (1 + K)$$

$$= KV_1 + V_1 (1 + K)^2$$

$$= V_1 [K + (1 + K)^2]$$

$\therefore \quad V_3 = V_1 [1 + 3K + K^2]$




Voltage between conductor and earth (*i.e.*, tower) is

$$V = V_1 + V_2 + V_3$$

$$= V_1 + V_1(1 + K) + V_1 (1 + 3K + K^2)$$

$$= V_1 (3 + 4K + K^2)$$

$\therefore \quad V = V_1(1 + K)(3 + K)$

From expressions (*i*), (*ii*) and (*iii*), we get,

$$\frac{V_1}{1} = \frac{V_2}{1 + K} = \frac{V_3}{1 + 3K + K^2} = \frac{V}{(1 + K)(3 + K)}$$

$\therefore$ Voltage across top unit, $\quad V_1 = \dfrac{V}{(1 + K)(3 + K)}$

Voltage across second unit from top, $V_2 = V_1 (1 + K)$

Voltage across third unit from top, $V_3 = V_1 (1 + 3K + K^2)$

$$\text{\%age String efficiency} = \frac{\text{Voltage across string}}{n \times \text{Voltage across disc nearest to conductor}} \times 100$$

$$= \frac{V}{3 \times V_3} \times 100$$

The following points may be noted from the above mathematical analysis :

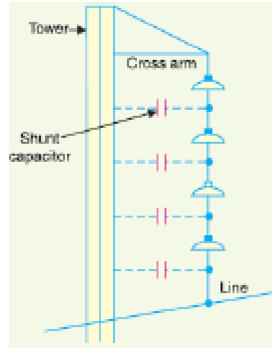
(*i*) If $K = 0{\cdot}2$ (Say), then from exp. (*iv*), we get, $V_2 = 1{\cdot}2\ V_1$ and $V_3 = 1{\cdot}64\ V_1$. This clearly shows that disc nearest to the conductor has maximum voltage across it; the voltage across other discs decreasing progressively as the cross-arm in approached.

(*ii*) The greater the value of $K$ (= $C_1/C$), the more non-uniform is the potential across the discs and lesser is the string efficiency.

(*iii*) The inequality in voltage distribution increases with the increase of number of discs in the string. Therefore, shorter string has more efficiency than the larger one.

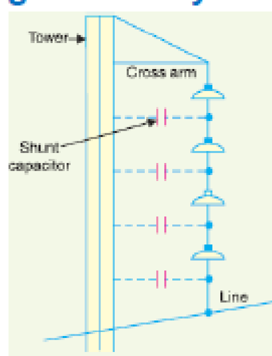
## Methods of Improving String Efficiency

**1.By using longer cross-arms.** The value of string efficiency depends upon the value of K i.e., ratio of shunt capacitance to mutual capacitance. The lesser the value of K, the greater is the string efficiency and more uniform is the voltage distribution. The value of K can be decreased by reducing the shunt capacitance. In order to reduce shunt capacitance, the distance of conductor from tower must be increased i.e., longer cross-arms should be used. However, limitations of cost and strength of tower do not allow the use of very long cross-arms. In practice, K = 0·1 is the limit that can be achieved by this method.



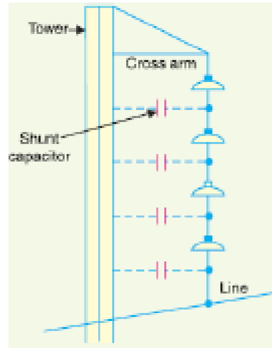

## Methods of Improving String Efficiency

**2.By grading the insulators.** In this method, insulators of different dimensions are so chosen that each has a different capacitance. The insulators are capacitance graded i.e. they are assembled in the string in such a way that the top unit has the minimum capacitance, increasing progressively as the bottom unit (i.e., nearest to conductor) is reached. Since voltage is inversely proportional to capacitance, this method tends to equalize the potential distribution across the units in the string. This method has the disadvantage that a large number of different-sized insulators are required. However, good results can be obtained by using standard insulators for most of the string and larger units for that near to the line conductor.



## Methods of Improving String Efficiency

**1.By using a guard ring.** The potential across each unit in a string can be equalised by using a guard ring which is a metal ring electrically connected to the conductor and surrounding the bottom insulator. The guard ring introduces capacitance between metal fittings and the line conductor. The guard ring is contoured in such a way that shunt capacitance currents i1, i2 etc. are equal to metal fitting line capacitance currents i'1, i'2 etc. The result is that same charging current I flows through each unit of string. Consequently, there will be uniform potential distribution across the units.

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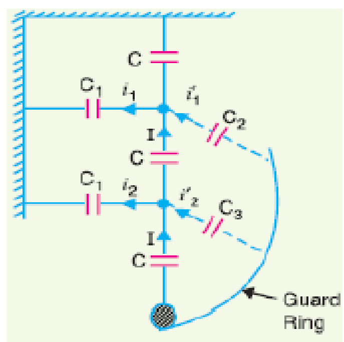
## Methods of Improving String Efficiency




$$\boldsymbol{V_2\,(C + C_2) - V_1\,(C + C_1) + V_3 C_2 = 0}$$

$$\boldsymbol{V_3(\,C + C_3\,) - V_2\,(\,C + C_1) - V_1 C_1 = 0}$$

$$\boldsymbol{V_{ph} = V_1 + V_2 + V_3}$$

11 , 131 , 1651

$$V_4 = (1 + 6k + 5k^2 + k^3)V_1$$

$$K_p = \frac{KCP}{n - P}$$

# Sag of Transmission Lines

- The sag of the conductor (vertical distance between the highest and lowest point of the curve) varies depending on the temperature and additional load such as ice cover.

## Sag of T.L depends on:

- **Conductor weight.**
- **Span length,**
- **Tension in the conductor, T**
- **Weather conditions (wind , ice).**
- **Temperature.**

## Sag and Tension in Overhead Transmission Line

While erecting an overhead line, it is very important that conductors are under safe tension.

If the conductors are too much stretched between supports in a bid to save conductor material, the stress in the conductor may reach unsafe value and in certain cases the conductor may break due to excessive tension.

In order to permit safe tension in the conductors, they are not fully stretched but are allowed to have a dip or sag.

## Calculation of Sag

In an overhead line, the sag should be so adjusted that tension in the conductors is within safe limits. The tension is governed by conductor weight, effects of wind, ice loading and temperature variations. It is a standard practice to keep conductor tension less than 50% of its ultimate tensile strength i.e., minimum factor of safety in respect of conductor tension should be 2.

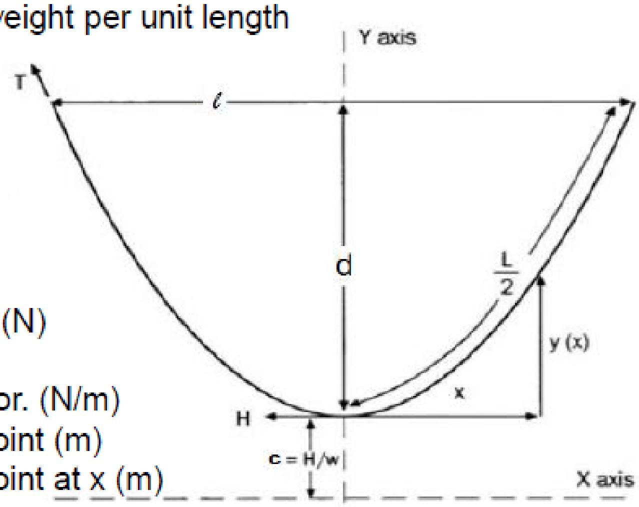
**We shall now calculate sag and tension of a conductor when**

(i) supports are at equal levels and

(ii) supports are at unequal levels.

## (i) When supports are at equal levels

The shape of a hanging line attached in its two ends can be described as a function of horizontal tension and weight per unit length




where
S = Sag (m)
L = Span length (m)
H = Horizontal component of tension (N)
T = Total tension (N)
w = weight per unit length of conductor. (N/m)
x = horizontal distance from lowest point (m)
y(x) = vertical distance from lowest point at x (m)

Fig. Illustrates the meaning of sag, span length and line length,

The following points may be noted:

(i) When the conductor is suspended between two supports at the same level, it takes the shape of catenary.

However, if the sag is very small compared with the span, then sag-span curve is like a parabola.

(ii) The tension at any point on the conductor acts tangentially. Thus tension H at the lowest Point O acts horizontally as shown in Fig. (ii).

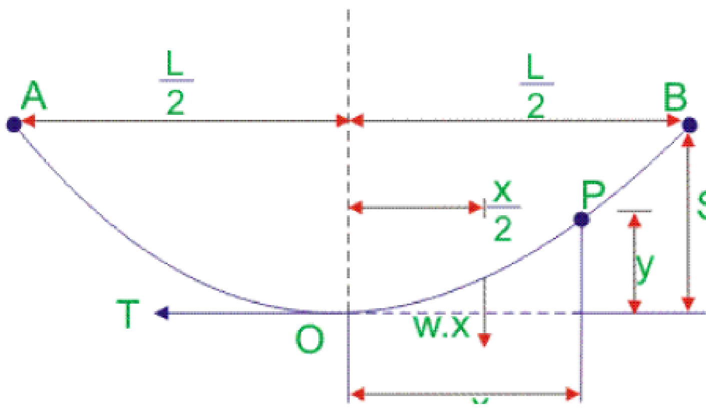
(iii) The horizontal component of tension is constant throughout the length of the wire.

(iv) The tension at supports is approximately equal to the horizontal tension acting at any point on the wire. Thus if T is the tension at the support B, then T = H.

The shape of the hanging line can be described with an approximate parabolic equation or with a more exact hyperbolic catenary equation.

The error due to parabolic approximation is very small except for very long, steep or deep spans.

The parabolic equation, has the advantages that it easily shows the relationships between sag, tension, weight and span length.




(a) The weight wx of conductor acting at a distance x/2 from O.

(b) The tension T acting at O.

Equating the moments of above two forces about point O, we get,

$$Ty = wx \times \frac{x}{2}$$

$$y = \frac{wx^2}{2T}$$

The maximum dip (sag) is represented by the value of y at either of the supports A & B.

At supports A $\qquad x = \frac{l}{2}$ $\qquad$ and $y = s$

$$\text{Sag S} = \frac{wl^2}{8T}$$

## Effect of ice and wind loading

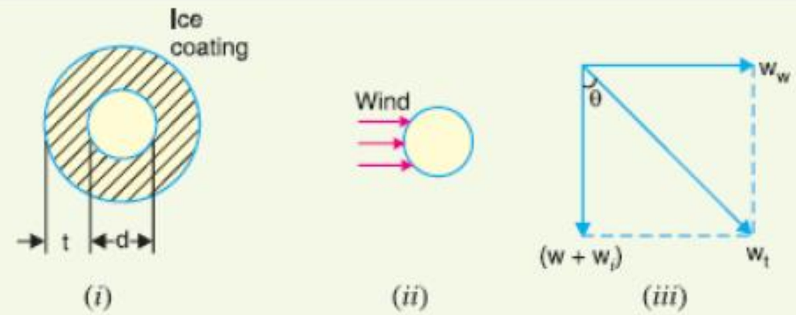



**Fig. 8.26**

Total weight of conductor per unit length is

$$w_t = \sqrt{(w + w_i)^2 + (w_w)^2}$$

where $w$ = weight of conductor per unit length
= conductor material density × volume per unit length

$w_i$ = weight of ice per unit length
= density of ice × volume of ice per unit length
= density of ice × $\frac{\pi}{4}[(d+2t)^2 - d^2] \times 1$
= density of ice × $\pi\, t\,(d+t)$*

$w_w$ = wind force per unit length
= wind pressure per unit area × projected area per unit length
= wind pressure × $[(d + 2t) \times 1]$

## Effect of ice and wind loading

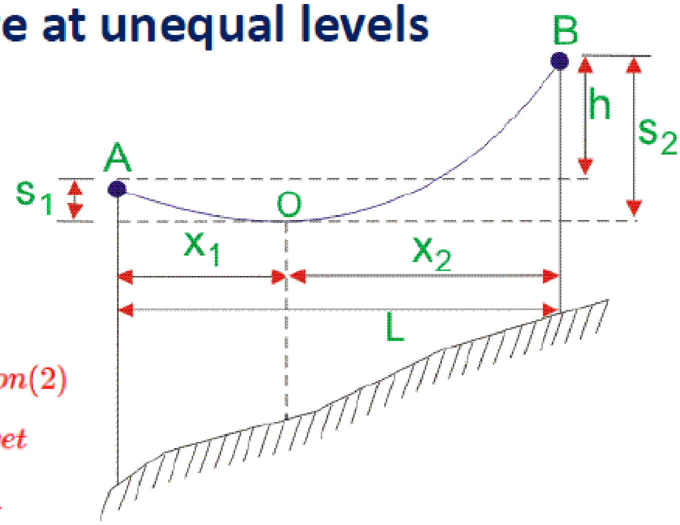
The sag in the conductor is give bv

$$S = \frac{w_t L^2}{2T}$$

So the vertical sag

$$S_v = S \cos\theta$$

## (ii) When supports are at unequal levels




$$Sag\ S_1 = \frac{wx_1^2}{2T}\ \ And\ Sag\ S_2 = \frac{wx_2^2}{2T}$$

$$Also,\ x_1 + x_2 = L \ldots\ldots\ldots equation(1)$$

$$Now,\ S_2 - S_1 = \frac{w}{2T}(x_2^2 - x_1^2) = \frac{w}{2T}(x_2 - x_1)(x_2 + x_1)$$

$$So,\ S_2 - S_1 = \frac{wL}{2T}(x_2 - x_1)$$

$$Again, S_2 - S_1 = h$$

$$So, h = \frac{wL}{2T}(x_2 - x_1)$$

$$Or,\ (x_2 - x_1) = \frac{2Th}{wL} \ldots\ldots\ldots\ldots equation(2)$$

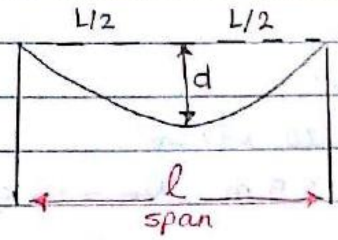
$$Solving\ equation\ (1)\ and\ (2),\ we\ get$$

$$x_1 = \frac{L}{2} - \frac{Th}{wL}\ and\ x_2 = \frac{L}{2} + \frac{Th}{wL}$$

report

# "Sag Calculation"

**The support at the same level**




span $\rightarrow$ L (m)

sag $\rightarrow$ d (m)

$W_c \rightarrow$ kg/m

$T \rightarrow$ kg

$W_w \rightarrow$ kg/m

$W_i \rightarrow$ kg/m

a $\rightarrow$ cross area

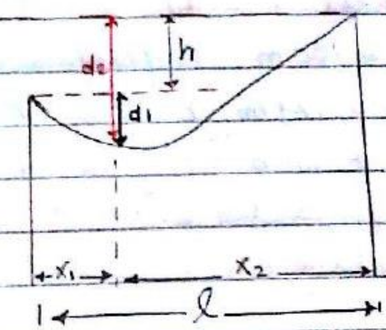
$$d = \frac{W_e L^2}{8T}$$

$$W_e = \sqrt{W_w^2 + (W_c + W_i)^2}$$

$$l_c = l\left(1 + \frac{W_e^2 l^2}{24 T^2}\right)$$

$$\boxed{\text{safty factor} = \frac{\text{breaking stress}}{T}}$$

**The support in different level**



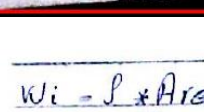

$$d_1 = \frac{W_e X_1^2}{2T}$$

$$d_2 = \frac{W_e X_2^2}{2T}$$

$$X_1 = \frac{L}{2} - \frac{T \cdot h}{W_e L}$$

$$X_2 = L - X_1 = \frac{L}{2} + \frac{T \cdot h}{W_e L}$$

$W_i = \rho \ast Area \rightarrow$ kg/m



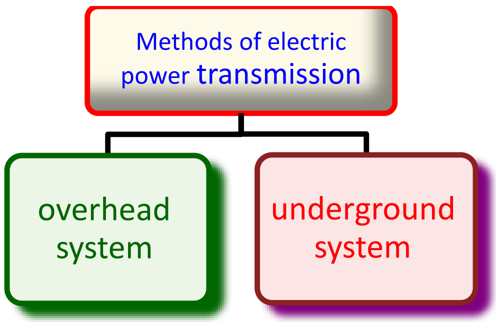

$$Area = \frac{\pi (D+2t)^2}{4} - \pi \frac{D^2}{4}$$

a $\rightarrow$ No ice $= \pi \frac{D^2}{4}$

a $\rightarrow$ ice $= \pi \frac{(D+2t)^2}{4} - \pi \frac{D^2}{4}$

## Transmission and Distribution of D.C. Power

By transmission and distribution of electric power is meant its conveyance from the central station, where it is generated, to places where it is demanded by the consumers like mills, factories, residential and commercial buildings, pumping stations etc.




## 12.6 Overhead Versus Underground System

The distribution system can be overhead or underground. Overhead lines are generally mounted on wooden, concrete or steel poles which are arranged to carry distribution transformers in addition to the conductors. The underground system uses conduits, cables and manholes under the surface of streets and sidewalks. The choice between overhead and underground system depends upon a number of widely differing factors. Therefore, it is desirable to make a comparison between the two.

(*i*) *Public safety.* The underground system is more safe than overhead system because all distribution wiring is placed underground and there are little chances of any hazard.

(*ii*) *Initial cost.* The underground system is more expensive due to the high cost of trenching, conduits, cables, manholes and other special equipment. The initial cost of an underground system may be five to ten times than that of an overhead system.

(*iii*) *Flexibility.* The overhead system is much more flexible than the underground system. In the latter case, manholes, duct lines etc., are permanently placed once installed and the load expansion can only be met by laying new lines. However, on an overhead system, poles, wires, transformers etc., can be easily shifted to meet the changes in load conditions.

(*iv*) *Faults.* The chances of faults in underground system are very rare as the cables are laid underground and are generally provided with better insulation.

(*v*) *Appearance.* The general appearance of an underground system is better as all the distribution lines are invisible. This factor is exerting considerable public pressure on electric supply companies to switch over to underground system.

(vi) *Fault location and repairs.* In general, there are little chances of faults in an underground system. However, if a fault does occur, it is difficult to locate and repair on this system. On an overhead system, the conductors are visible and easily accessible so that fault locations and repairs can be easily made.

(vii) *Current carrying capacity and voltage drop.* An overhead distribution conductor has a considerably higher current carrying capacity than an underground cable conductor of the same material and cross-section. On the other hand, underground cable conductor has much lower inductive reactance than that of an overhead conductor because of closer spacing of conductors.

(viii) *Useful life.* The useful life of underground system is much longer than that of an overhead system. An overhead system may have a useful life of 25 years, whereas an underground system may have a useful life of more than 50 years.

(ix) *Maintenance cost.* The maintenance cost of underground system is very low as compared with that of overhead system because of less chances of faults and service interruptions from wind, ice, lightning as well as from traffic hazards.

(x) *Interference with communication circuits.* An overhead system causes electromagnetic interference with the telephone lines. The power line currents are superimposed on speech currents, resulting in the potential of the communication channel being raised to an undesirable level. However, there is no such interference with the underground system.

| Parameter | Underground | Overhead |
|---|---|---|
| Public Safety | Win | Lose |
| Initial Cost | Lose | Win |
| faults | win | Lose |
| Fault location | lose | Win |
| appearance | win | Lose |
| flexibility | lose | Win |
| Current carrying capacity | lose | Win |
| maintenance | win | Lose |
| Useful life | Win 50 | Lose 25 |
| Interference with commu | win | Lose |

## Transmission and Distribution of D.C. Power

A good system whether overhead or underground should fulfill the following requirements

Voltage at consumer's terminals must be within ±5

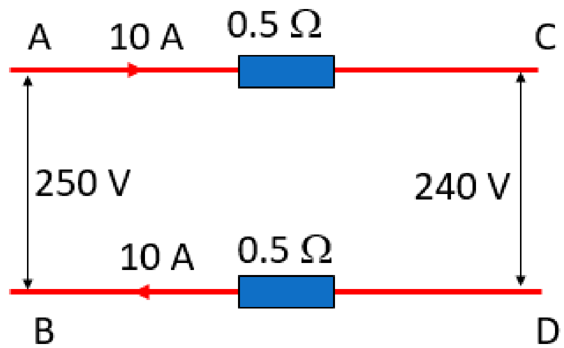
The loss of power in the system should be a small percentage (about 10%) of the power transmitted

The transmission cost should not be excessive

Maximum current through the conductor is limited to prevent conductor overheating and insulation injury

# Voltage Drop and Transmission Efficiency

The difference in potential at the two ends is the potential drop in the cable




If the transmitting voltage is 250V, current in AC is 10A, and resistance of each feeder conductor is 0.5 Ω,

drop in each feeder conductor is 10*0.5 = 5 volt

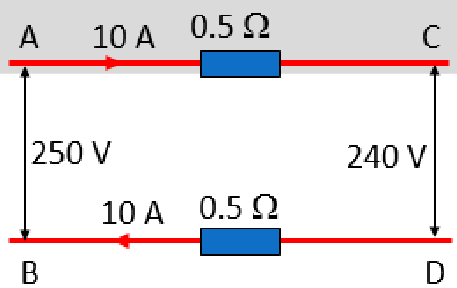
drop in both feeder conductors is 5 * 2 = 10 V

The potential difference at receiving end CD: 250 - 10 = 240 V

**Input power at *AB* = 250*10= 2500W**

**Output power at *CD* =240*10=2400W**

**power lost in 2 feeders=2500-2400=100W**



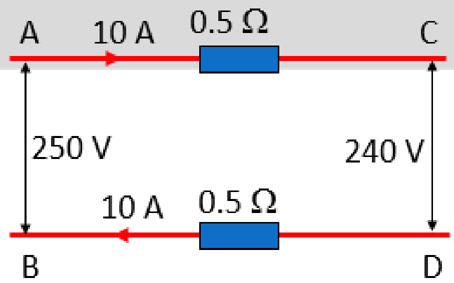

The power loss could also be found by using the formula:

Power loss = $2\, I^2 * R = 2 * 10^2 * 0.5 = 100W$

The transmission efficiency is the ratio of output to input:

$$\text{Efficiency of the transmission} = \frac{\textit{Power delivered to the line}}{\textit{Power received by the line}}$$

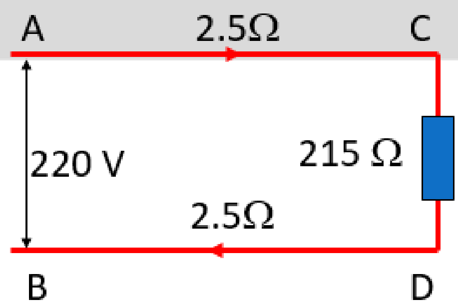
$$\eta = \frac{\text{Power delivered to the line}}{\text{Power received by the line}}$$




Power delivered by the *feeder* is 2400W and power received is 2500W

$\eta = 2400*100/2500 = 96\%$

**Example:** A DC 2-wire feeder supplies a constant load with a sending-end voltage of 220 V. If the load resistance is 215 Ω and the total feeder resistance is 5Ω, calculate the load voltage, voltage drop, and feeder efficiency.



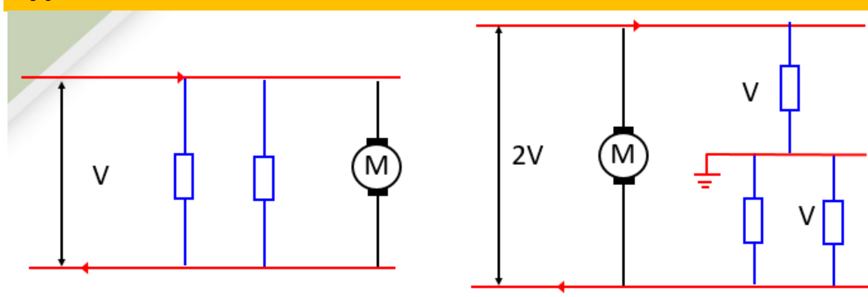

**Solution**: $I = V_1/(R_t + R_L) = 220/(5+215) = 1A$

Voltage drop $= I * R_t = 1*5 = 5$ V

$V_2 = V_1$ - Voltage drop $= 220-5 = 215$ V.

$\%\eta = (V_2\, I/V_1\, I)*100 = (V_1/V_2)*100 = 215/220*100 = 97.73\%$

## Types of DC distribution

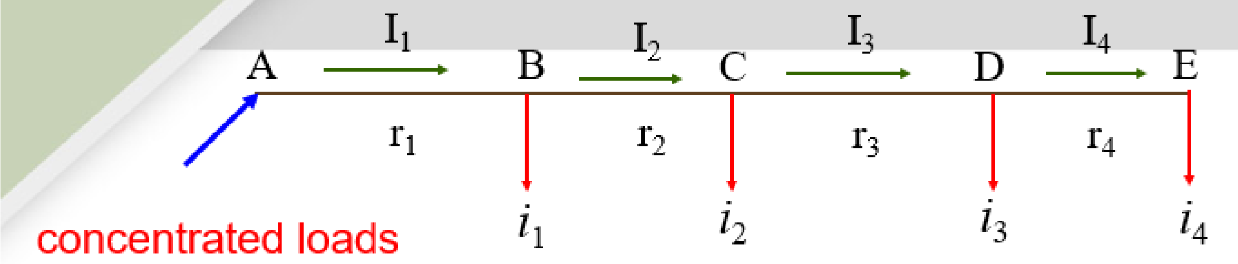



a) 2-wire system b) 3-wire system

# Methods of Feeding a Distributor

- Feeding at one end
- Feeding at both ends with equal voltages
- Feeding at both ends with unequal voltages
- Ring distributor

## D.C. distributor fed at one end




$$\mathbf{I_1 = i_1 + i_2 + i_3 + i_4} \qquad \mathbf{I_2 = i_2 + i_3 + i_4}$$

$$\mathbf{I_3 = i_3 + i_4} \qquad \mathbf{I_4 = i_4}$$

$$\Delta \mathrm{V} = \mathbf{I_1 * r_1 + I_2 * r_2 + I_3 * r_3 + I_4 * r_4}$$

$$\Delta \mathrm{V} = r_1 (i_1 + i_2 + i_3 + i_4) + r_2 (i_2 + i_3 + i_4) + r_3 (i_3 + i_4) + r_4 i_4$$

# Distributor fed at both ends

**It is desirable for long distributors to be fed at both ends instead of at one end**

**Feeding at both ends reduces the voltage drop without increasing the cross-section of the conductor**

**The two ends of the distributor may be supplied with:**

**(i) Equal voltages** **(ii) Unequal voltages**

*Advantages*

(*a*) If a fault occurs on any feeding point of the distributor, the continuity of supply is maintained from the other feeding point.

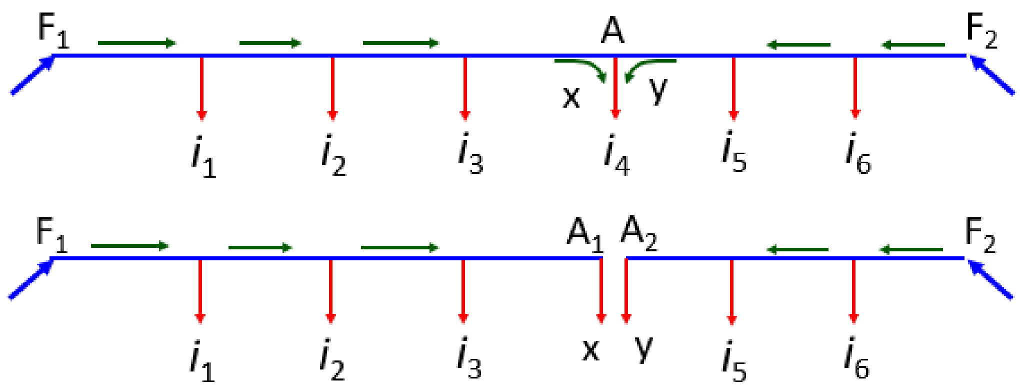
(*b*) In case of fault on any section of the distributor, the continuity of supply is maintained from the other feeding point.

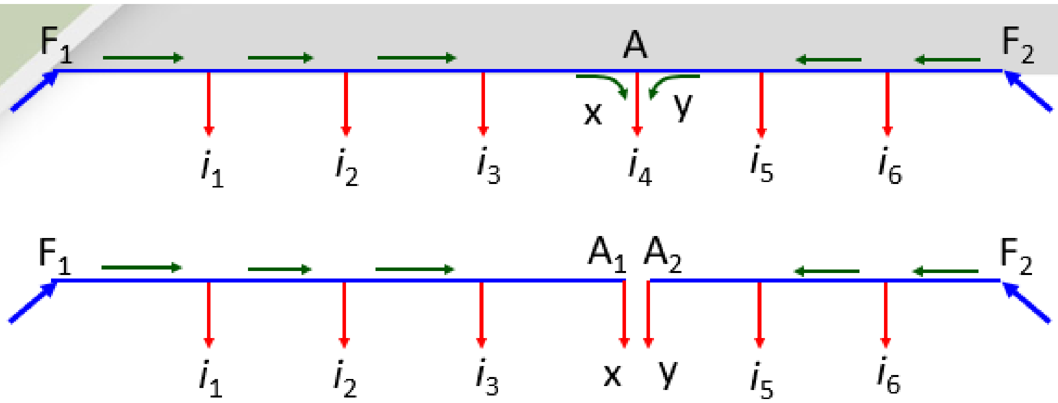
(*c*) The area of X-section required for a doubly fed distributor is much less than that of a singly fed distributor.

## Distributor fed at both ends with equal voltages

(i) the maximum voltage drop must always occur at one of the load points

(ii) since both feeding ends are at the same potential, then the voltage drop between each end and this point must be the same




$x + y = i_4$

drop from $F_1$ to $A_1$ = drop from $F_2$ to $A_2$

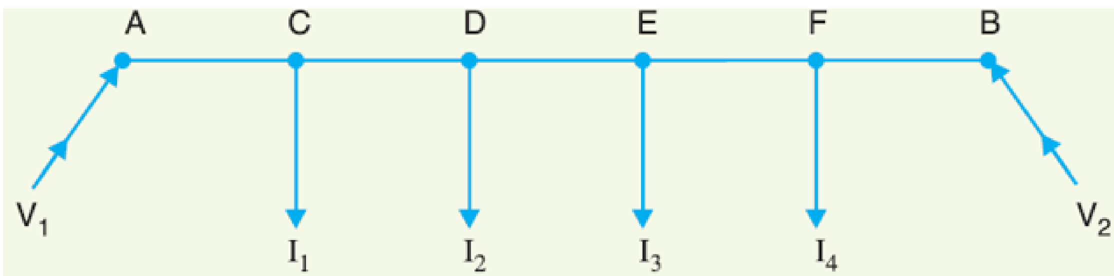
Total voltage drop from $F_1$ to $F_2$ = 0.0

## Distributor fed at both ends with unequal voltages

The point of minimum potential can be found by following the same procedure as discussed above

Voltage drop between A and B =Voltage drop over AB

$V_1 - V_2$ = Voltage drop over AB

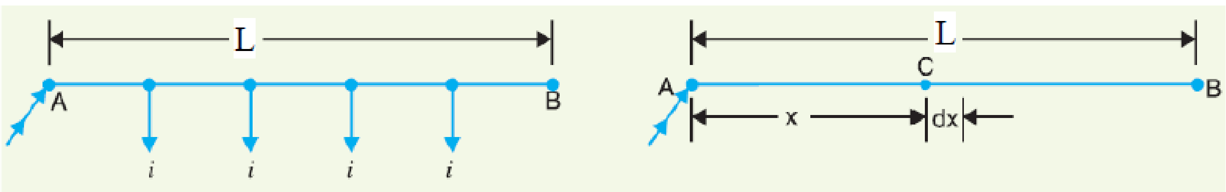


## Uniformly Loaded Distributor Fed at One End

The 2-wire d.c. distributor AB is fed at one end A and loaded uniformly with i amperes per metre length

At every 1 m length of the distributor, the load tapped is i amperes

Let L meters be the length of the distributor and r ohm be the resistance per meter run.




Point C on the distributor at a distance "x" m from the feeding point A

Current at point C is = i . L − i . x = i (L − x) A

For a small length dx, the resistance is r dx

The voltage drop over length dx is:

dv = i (L− x) r dx = i r (L-x) dx

Voltage drop to point C: $v = \int_0^x i\,r\,(L - x)\,dx = i\,r\left(L\,x - \frac{x^2}{2}\right)$

To get the voltage drop to point B, put x = L

template3

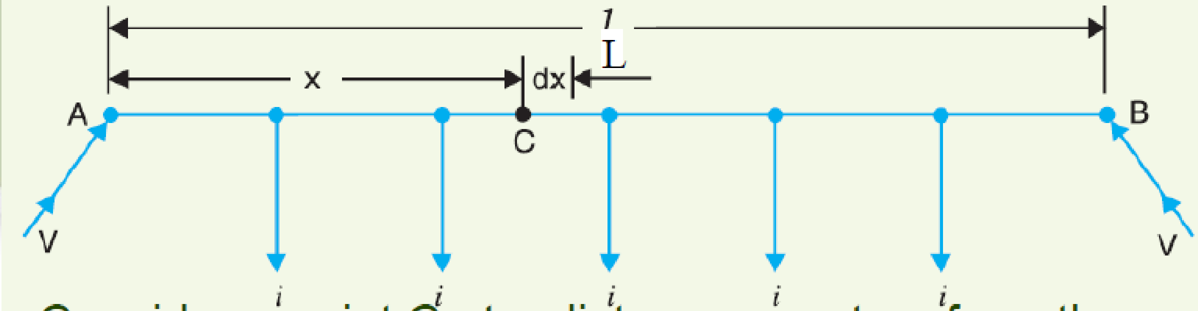
Voltage drop for distributor AB $= i\,r\left(L \times L - \frac{L^2}{2}\right)$

Voltage drop for AB = 0.5 (i L)(r L) = 0.5 I R

(similar to the same load concentrated at the middle point)

## Uniformly Loaded Distributor Fed at Both Ends

Distributor fed at both ends with equal voltages




Consider a point C at a distance x meters from the feeding point A

Then current at point C is $= \dfrac{iL}{2} - i\,x = i\left(\dfrac{L}{2} - x\right)$

- $dV = i\left(\frac{L}{2} - x\right) r dx = ir\left(\frac{L}{2} - x\right) dx$
- Voltage drop at point C $= \int_0^x ir\left(\frac{L}{2} - x\right) dx = \frac{ir}{2}(Lx - x^2)$

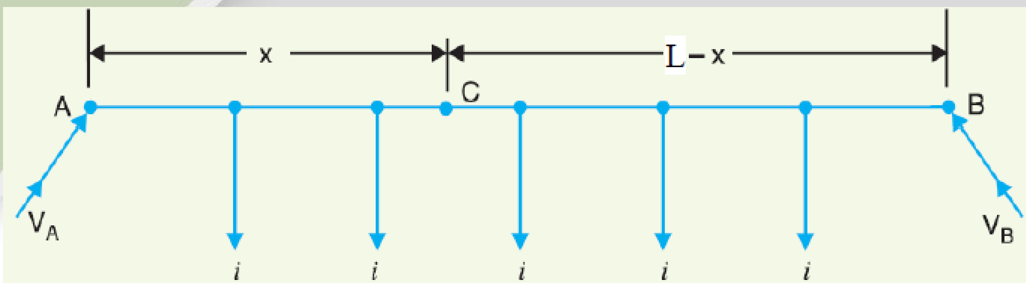
Maximum voltage drop will occur at mid-point i.e. where x = L/2

Max. voltage drop $= \dfrac{ir}{2}\left(Lx - x^2\right)$

$$= \frac{ir}{2}\left(L \times \frac{L}{2} - \frac{L^2}{4}\right) = \frac{1}{8}\, i\, r L^2 = \frac{1}{8}(iL)(rL) = \boxed{\frac{1}{8}\, I\, R}$$

$$\text{Minimum voltage} = V - \frac{I\,R}{8} \text{ volts}$$

## Distributor fed at both ends with unequal voltages




Voltage drop in section AC = 0.5 i r $x^2$

As the distance of C from feeding point B is (L − x), current fed from B is i (L − x)

Voltage drop in section BC = $\dfrac{i\,r\,(L-x)^2}{2}$ volts

Voltage at point C, VC

=VA − Drop over AC = $V_A - \dfrac{i\,r\,x^2}{2}$

Also, voltage at point C, VC

=VB − Drop over BC $= V_B - \dfrac{i\,r\,(L-x)^2}{2}$

$$V_A - \frac{i\,r\,x^2}{2} = V_B - \frac{i\,r\,(L-x)^2}{2}$$

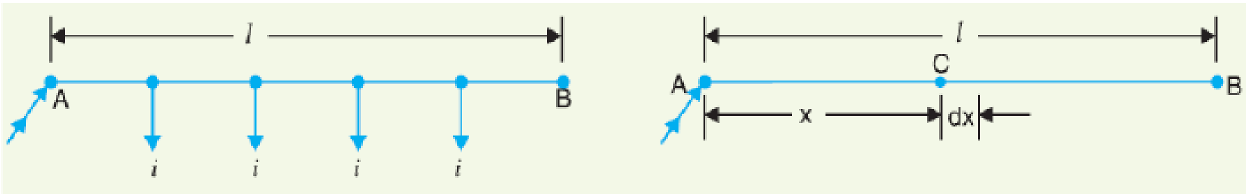
Solving for x, we get, $x = \dfrac{V_A - V_B}{i\,r\,L} + \dfrac{L}{2}$

## 1- Feeding at one end

L : the length of distributer in (m)

r : the resistance per meter run (ohm )

Point C on the distributer at a distance “x” from the feeding point A




$$\therefore current\ at\ point\ c\ is\ =\ i*L-i*x=i(L-x)\quad A$$

$$the\ resistance\ for\ a\ very\ smal\ lenght=rdx\quad \Omega$$

$$\therefore the\ voltage\ drop\ across\ it=\ \ dv=i(L-x)*rdx=ir(L-x)dx$$

$$\therefore V=\int_0^x ir(L-x)dx=ir\left(Lx-\frac{x^2}{2}\right)$$

$$the\ Max\ voltage\ drop(at\ x=L\ )=ir\left(L^2-\frac{L^2}{2}\right)=0.5\ IR\qquad Volt$$

$$\boldsymbol{The\ Min.Voltage=V_A-0.5\ IR\qquad Volt}$$

$$the\ Power\ Losses=I^2R\ =\ [i(L-x)]^2*rdx\ =dP$$

$$\therefore \int dP\ =\int_0^x i^2r\,[L^2+x^2-2Lx\,]\,dx\ =i^2r\left[L^2x+\frac{x^3}{3}-Lx^2\right]$$

$$\therefore P=\ i^2r\left[L^2x+\frac{x^3}{3}-Lx^2\right]$$

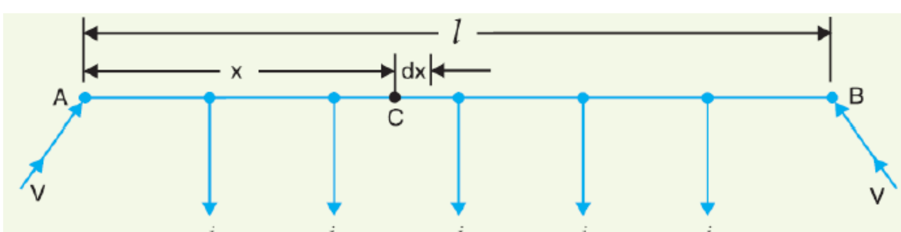
$$\boldsymbol{\therefore P_L=\ i^2r\left[L^3+\frac{L^3}{3}-L^3\right]\ =\frac{1}{3}\,i^2L^2*rL=\frac{1}{3}i^2rL^3=\frac{1}{3}I^2R\qquad watt}$$

## 2. Feeding at both ends with equal voltage

The distributer is fed at both ends A and B at equal Voltge ( V )

the current supplied from each feeding point = $i*\frac{L}{2}$

Point C at distance “x” from the feeding point A



$$the\ current\ at\ point\ c\ is\ \frac{iL}{2} - ix = i\left(\frac{L}{2} - x\right)$$

$$\therefore dv = i\left(\frac{L}{2} - x\right) r dx = ir\left(\frac{L}{2} - x\right) dx$$

$$\therefore Voltage\ drop\ at\ point\ c = \int_0^x ir\left(\frac{1}{2} - x\right) dx = \frac{ir}{2}(Lx - x^2)$$

$$Max\ \ voltage\ drop\ is\ at\ mid\ point\ \left(at\ x = \frac{L}{2}\right)$$

$$\therefore \boldsymbol{Min\ voltage = V - \frac{ir}{8}L^2 = V - \frac{IR}{8}\ \ volts}$$

$$\because \int dP = [\ i\left(\frac{L}{2} - x\right)\hat{}2\ rdx = \int_0^x i^2 r\left[\frac{L^2}{4} + x^2 - Lx\right] dx$$

$$\therefore P_{Losses} = i^2 r\left[\frac{L^2 x}{4} + \frac{x^3}{3} - \frac{Lx^2}{2}\right]$$

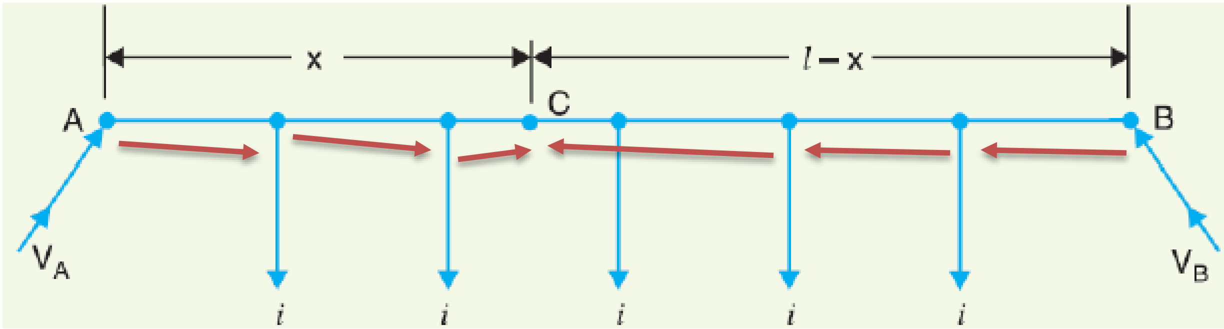
$$\therefore total\ Power\ Losses = i^2 r\left[\frac{L^3}{8} + \frac{L^3}{24} - \frac{L^3}{8}\right]$$

$$\therefore \boldsymbol{Total\ \ Power\ Losses = \frac{i^2 r L^3}{12} = \frac{1}{24} I^2 R}$$

## 3. Feeding at both ends with unequal voltages

The distributer is fed at both ends A and B at unequal
the current supplied from each feeding point = $i * \frac{L}{2}$

Point C at distance "x" from the feeding point A and at the min. voltage so the direction of current is reversed at this point




$$V_{AC} = \frac{ir^2}{2}\,x^2 \qquad ; \qquad V_C = V_A - \frac{ir}{2}x^2$$

$$V_{BC} = \frac{ir}{2}\,(L-x)^2 \qquad ; \qquad V_c = V_B - \frac{ir}{2}(L-x)^2$$

$$\boldsymbol{(Min\,Voltage\,from\,A) = (Min\,Voltage\,from\,B)}$$

$$\therefore \boldsymbol{V_C = V_A - \frac{ir}{2}x^2 \qquad = \qquad V_B - \frac{ir}{2}(L-x)^2}$$

$$solving\,for\,x$$

$$\therefore x = \frac{V_A - V_B}{irL} + \frac{L}{2}$$

Getting the Power dissipated we can get it from our information of the case before where

$$\boldsymbol{P_1 = \frac{i^2r}{3}x^3 \qquad P_2 = \frac{i^2r}{3}\,(L-x)^3}$$

$$\therefore \boldsymbol{P_{total} = P_1 + P_2}$$

## Ring Distributor

A distributor arranged to form a closed loop and fed at one or more points is called a ***ring distributor.***

Such a distributor starts from one point, makes a loop through the area to be served, and returns to the original point

The distributor can be considered as consisting of a series of open distributors fed at both ends

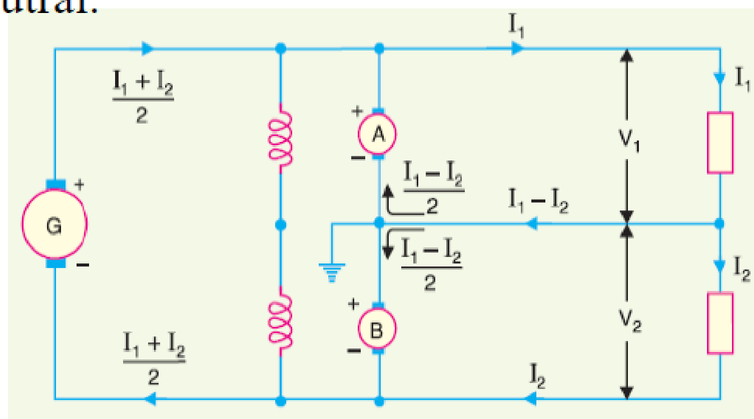
The principal advantage of ring distributor is that by proper choice in the number of feeding points, great economy in copper can be affected

## Balancers in 3-Wire D.C. System

- The neutral wire is connected to the junction of the armatures.
- The circuit arrangement has two obvious advantages.

1. Only one generator (G) is required which results in a great saving in cost.
2. The balancer set tends to equalize the voltages on the two sides of the neutral.

$$E = V + I_a R_a$$
$$E > V \quad (G)$$
$$E = V \quad (no\ load)$$
$$E < V \quad (M)$$




Elements of Power system

## Elements of Power System

It has already been pointed out that for transmission of electric power, 3-phase, 3-wire a.c. system is universally adopted. However, other systems can also be used for transmission under special circumstances. ***The different possible systems of transmission are:***

**1. D.C. system**
***(i)*** D.C. two-wire.
***(ii)*** D.C. two-wire with mid-point earthed.
***(iii)*** D.C. three-wire.

**2. Single-phase A.C. system**
***(i)*** Single-phase two-wire.
***(ii)*** Single-phase two-wire with mid-point earthed.
***(iii)*** Single-phase three-wire.

**3. Two-phase A.C. system**
***(i)*** Two-phase four-wire.
***(ii)*** Two-phase three wire.

**4. Three-phase A.C. system**
***(i)*** Three-phase three-wire.
***(ii)*** Three-phase four-wire.

**A.C. distribution differ from D.C. distribution in:**

1. The voltage drops are due to the combined effects of resistance, inductance and capacitance
2. The additions and subtractions of currents or voltages are done vectorially
3. The power factor (p.f.) has to be taken into account. Loads tapped off from the distributor are generally at different power factors.

**Method of solving A.C. distribution problems**

There are two ways of referring power factor:

1. It may be referred to supply or receiving end voltage which is regarded as the reference vector
2. It may be referred to the voltage at the load point itself

**Power Calculation:**

For $v = V_m \cos(\omega t + \theta_v)$ ; $i = I_m \cos(\omega t + \theta_i)$ ; $\theta = |\theta_v - \theta_i|$

$$\therefore \quad P = \frac{V_m I_m}{2} \cos\theta$$

$$where \quad Power\ Factor = PF = \cos\theta$$

$$\boldsymbol{Inductive\ Load : Current\ lags\ Voltage : Lagging\ PF\ : \theta_v - \theta_i = +ve}$$
$$\boldsymbol{Capacitive\ Load : Current\ Leads\ Voltage : Leading\ PF : \theta_i - \theta_v = -ve}$$

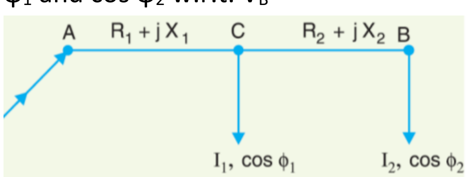
**Examples of different power factor referreing**

The power factors of load currents may be given:

1. Power factors referred to receiving or sending end voltage, or
2. Power factors referred to load voltage itself

***(i)*** Power factors referred to receiving end **voltage**

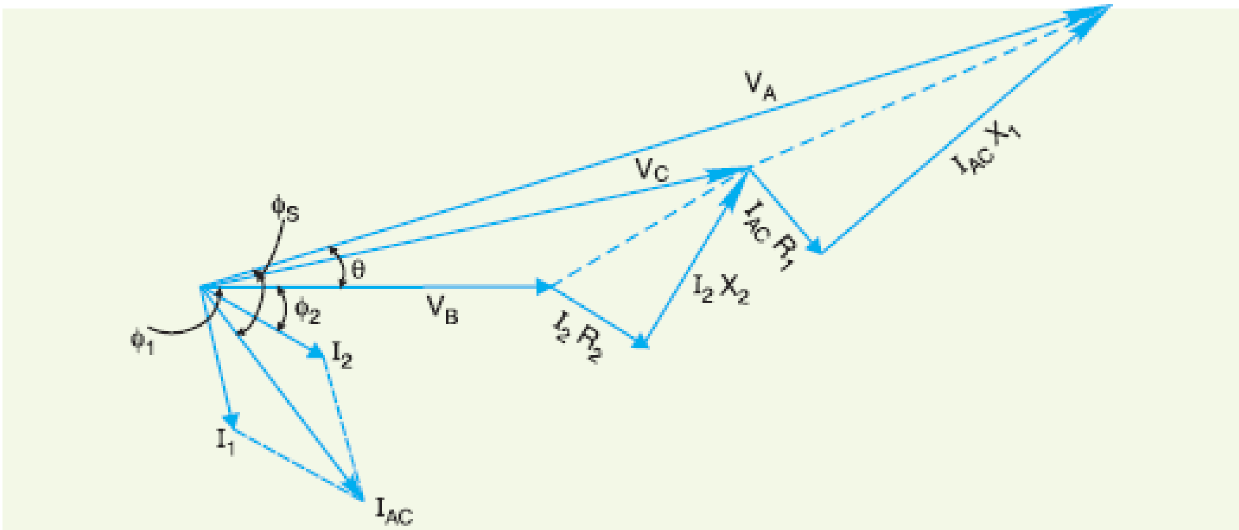
Taking receiving end voltage $V_B$ as reference vector and lag. power factors at C and B are cos $\phi_1$ and cos $\phi_2$ w.r.t. $V_B$




$$V_B\ refrence$$
$$\therefore \vec{I_2} = I_2 (\cos\phi_2 - j \sin\phi_2)$$

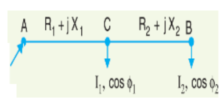
$$\vec{I_1} = I_1 (\cos\phi_1 - j\sin\phi_1)$$
$$\vec{I_{CB}} = \vec{I_2} = I_2 (\cos\phi_2 - j \sin\phi_2)$$
$$\vec{I_{AC}} = I_1 + I_2 = I_1 (\cos\phi_1 - j\sin\phi_1) + I_2 (\cos\phi_2 - j \sin\phi_2)$$

$$\overrightarrow{V_{CB}} = \overrightarrow{I_2}\, Z_2 = I_2\,(\cos\phi_2 - j\,\sin\phi_2)\,(R_2 + j\,X_2)$$
$$\overrightarrow{V_{AC}} = I_1\,(\cos\phi_1 - j\sin\phi_1) + I_2\,(\cos\phi_2 - j\,\sin\phi_2)\,[R_1 + jX_1]$$



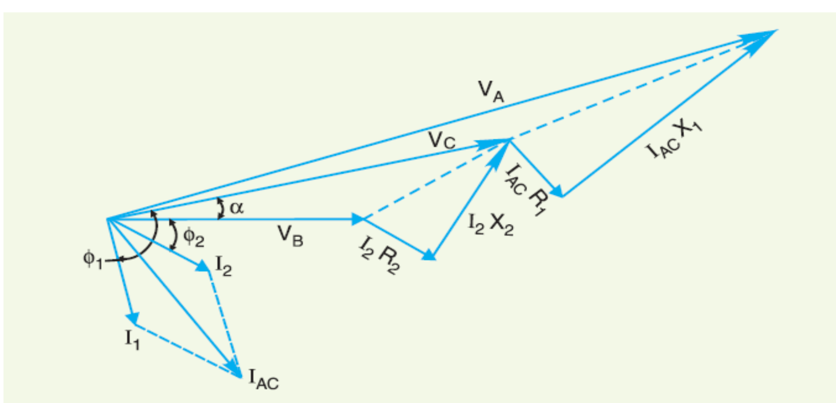

*(ii)* Power factors referred to respective load voltages

$\phi_1$ is the phase angle between $V_C$ and $I_1$ and $\phi_2$ is the phase angle between $V_B$ and $I_2$




$$\overrightarrow{I_2} = I_2(\cos\phi_2 - j\sin\phi_2)$$
$$assume\ \ V_C = V_c\angle\alpha$$

$$\therefore \overrightarrow{I_1} = I_1\,(\cos(\phi_1 - \alpha) - j\sin(\phi_1 - \alpha))$$




الخلاصه:

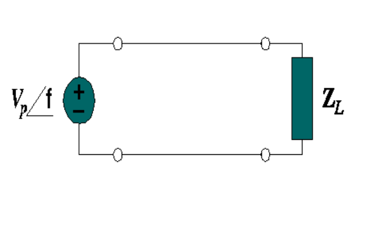
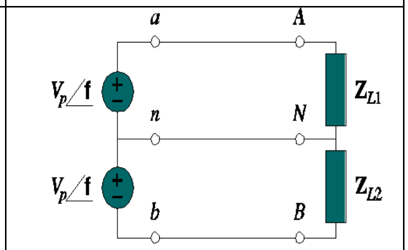
$\hat{I} = \hat{\phi} + \hat{V}$

$\phi$ ← توضع سالب في حالة Lag

$\phi$ ← توضع موجبا في حالة Lead

if lag (-) if lead (+)

$$I_1 = Magnitude\,\angle(\ \pm\ \cos^{-1} PF + \widehat{V_1}\ )$$

| SINGLE PHASE TWO WIRE | SINLGE PHASE THREE WIRE |
|---|---|
|   |   |
| • A generator connected through a pair of wire to a load – Single Phase Two Wire.<br>• Vp is the magnitude of the source voltage, and $\phi$ is the phase. | • Most common in practice: two identical sources connected to two loads by two outer wires and the neutral: Single Phase Three Wire.<br>• Terminal voltages have same magnitude and the same phase. |

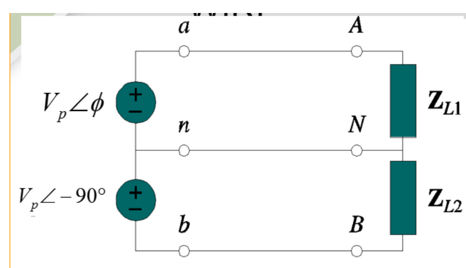
**POLYPHASE SYSTEM**

Circuit or system in which AC sources operate at the same frequency but different phases are known as polyphase.

1- <u>Two phase system THREE WIRE :</u>

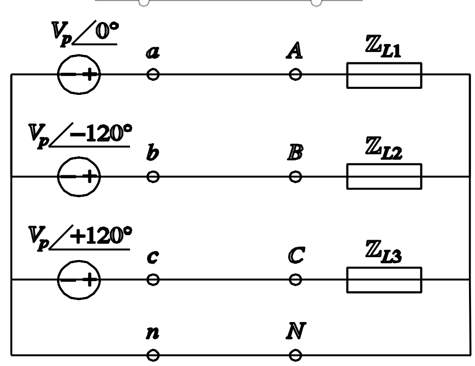
Two Phase System:

- A generator consists of two coils placed perpendicular to each other
- The voltage generated by one lags the other by 90°.




2- <u>Three Phase System:</u>

- A generator consists of <u>three coils</u> placed 120° apart.
- The voltage generated are equal in magnitude but, out of phase by 120°.
- Three phase is the most economical polyphase system.
- All electric power is generated and distributed in three phase.
  - One phase, two phase, or more than three phase input can be taken from three phase system rather than generated independently.




1three-phase 4-wire

- Melting purposes need 48 phases supply.

- <u>Importance of three phase system :</u>
  - Uniform power transmission and less vibration of three phase machines.
    - The instantaneous power in a 3ϕ system can be constant (not pulsating).
    - High power motors prefer a steady torque especially one created by a rotating magnetic field.
  - <u>Three phase system is more economical than the single phase.</u>
    - The amount of wire required for a three phase system is less than required for an equivalent single phase system.
    - Conductor: Copper, Aluminum, etc

**<u>BALANCED 3$\phi$ VOLTAGES</u>**

Balanced three phase voltages:

- same magnitude (VM )
- 120° phase shift

$$v_{an}(t) = V_M \cos(\omega t)$$
$$v_{bn}(t) = V_M \cos(\omega t - 120^\circ)$$
$$v_{cn}(t) = V_M \cos(\omega t - 240^\circ) = V_M \cos(\omega t + 120^\circ)$$

**<u>BALANCED 3 $\phi$ CURRENTS</u>**

Balanced three phase currents:

- same magnitude (IM )
- 120° phase shift

$$i_a(t) = I_M \cos(\omega t - \theta)$$
$$i_b(t) = I_M \cos(\omega t - \theta - 120^\circ)$$
$$i_c(t) = I_M \cos(\omega t - \theta - 240^\circ)$$

PHASE SEQUENCE

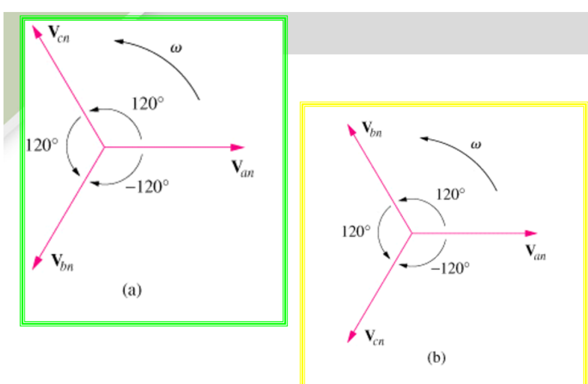
$$v_{an}(t) = V_M \cos \omega t$$
$$v_{bn}(t) = V_M \cos(\omega t - 120^\circ)$$
$$v_{cn}(t) = V_M \cos(\omega t + 120^\circ)$$

$$V_{an} = V_M \angle 0^\circ \qquad V_{bn} = V_M \angle -120^\circ \qquad V_{cn} = V_M \angle +120^\circ$$

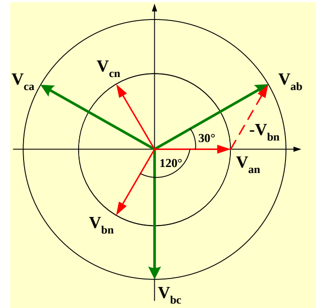
POSITIVE SEQUENCE

$$V_{an} = V_M \angle 0^\circ \qquad V_{bn} = V_M \angle +120^\circ \qquad V_{cn} = V_M \angle -120^\circ$$

NEGATIVE SEQUENCE



Phasor Diagram of $V_L$ $and$ $V_\phi$




$$\therefore \; V_\phi = \frac{V_L}{\sqrt{3}}$$

- **<u>Balanced Phase Voltage:</u>** all phase voltages are equal in magnitude and are out of phase with each other by 120°.
- **<u>Balanced Load:</u>** the phase impedances are equal in magnitude and in phase.
- **<u>Phase voltage</u>** is measured between the neutral and any line: line to neutral voltage
- **<u>Line voltage</u>** is measured between any two of the three lines: line to line voltage.
- **<u>Line current</u>** is the current in each line of the source or load.
- **<u>Phase current</u>** is the current in each phase of the source or load.

| QUANTITY | SYMBOL |
|---|---|
| Phase current | $I_\phi$ |
| Line current | $I_L$ |
| Phase voltage | $V_\phi$ |
| Line voltage | $V_L$ |

| SOURCE | LOAD | CONNECTION |
|---|---|---|
| Wye | Wye | Y-Y |
| Wye | Delta | Y-Δ |
| Delta | Delta | Δ- Δ |
| Delta | Wye | Δ-Y |

## Three-phase AC Distribution

1- Four-wire star-connected unbalanced load
2- Unbalanced delta-connected load
3- Unbalanced 3-wire, star-connected load

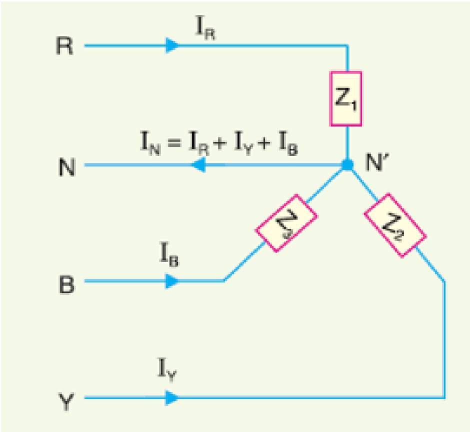
The 3-phase , 4-wire system is widely used for distribution of electric power in commercial and industrial buildings.

The single phase load is connected between any line and neutral wire while a 3-phase load is connected across the three lines.

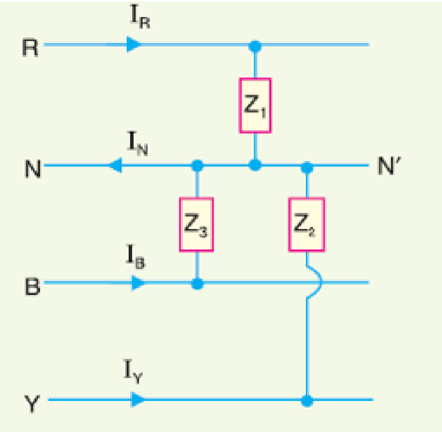
## Four-wire star-connected unbalanced load

Since the load is unbalanced, the line currents will be different in magnitude and displaced from one another by unequal angles. The current in the neutral wire will be the phasor sum of the three line currents i.e.

$$\bar{I}_N = \bar{I}_R + \bar{I}_B + \bar{I}_Y$$




Three phase load




single phase loads

# Comparison of Conductor Material in Overhead System

(i) same power (*P watts*) transmitted by each system.

(*ii*) the distance (*l metres*) over which power is transmitted remains the same.

(*iii*) the line losses (*W watts*) are the same in each case.

(*iv*) the maximum voltage between any conductor and earth (*Vm*) is the same in each case.

## Comparison of 3-wire and 2-wire D.C. distribution

- It will be shown that there is a great saving of conductor material if we use 3-wire system instead of 2-wire system for d.c. distribution.
- For comparison, it will be assumed that:

i. The amount of power $P$ transmitted is the same

ii. The voltage $V$ at the consumer's terminals is the same

iii. The distance of transmission is the same

iv. The efficiency of transmission (and hence losses) is the same

v. The 3-wire system is balanced i.e. no current in the neutral wire

vi. The area of X-section of neutral wire is half the cross-section of outers in 3-wire system

## Comparison of 3-wire and 2-wire D.C. distribution

Let $R_2$ = resistance of each conductor in 2-wire system

$R_3$ = resistance of each outer in 3-wire system

Current through outers in case of 3-wire system is

$$I_3 = \frac{P}{2V}$$

Total losses in two outers $\quad P_{loss} = 2I_3^2 R_3 = 2\left(\frac{P}{2V}\right)^2 R_3$

Current through conductor in case of 2-wire system is

$$I_2 = \frac{P}{V}$$

Total losses $\quad P_{loss} = 2I_2^2 R_2 = 2\left(\frac{P}{V}\right)^2 R_2$

Since efficiency of transmission is the same, it means losses are the same i.e.

## Comparison of 3-wire and 2-wire D.C. distribution

Since efficiency of transmission is the same, it means losses are the same i.e.

$$2\left(\frac{P}{2V}\right)^2 R_3 = 2\left(\frac{P}{V}\right)^2 R_2$$

$$R_3 = 4R_2$$

Therefore, the area of X-section of outers in 3-wire case will be one-fourth of each conductor in 2-wire system.

Let a = area of X-section of each conductor in 2-wire system

Then a/4 = area of X-section of each outer in 3-wire system

And a/8 = area of X-section of each neutral in 3-wire system

If L is the length of the line, then,

Volume of Cu for 3-wire system $= \mathrm{L}\left(\frac{a}{4}+\frac{a}{4}+\frac{a}{8}\right) = \frac{5}{8} a\, L$

## Comparison of 3-wire and 2-wire D.C. distribution

Volume of Cu for 2-wire system $= \mathrm{L}(\boldsymbol{a}+\boldsymbol{a}) = \boldsymbol{2a\,L}$

$$\frac{\textbf{Volume of Cu for 3-wire system}}{\textbf{Volume of Cu for 2-wire system}} = \frac{5}{8}a\,L \times \frac{1}{2a\,L} = \frac{5}{16}$$

Hence a 3-wire system requires only 5/16th (or 31.25%) as much copper as a 2-wire system.

**If the neutral has the same X-section as the outer, then,**

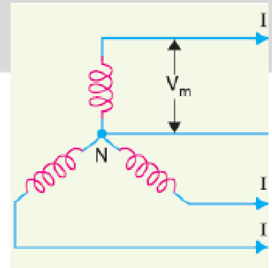
Volume of Cu for 3-wire system $= \mathrm{L}\left(\frac{a}{4}+\frac{a}{4}+\frac{a}{4}\right) = \frac{3}{4}\boldsymbol{a\,L}$

Volume of Cu for 2-wire system $= \mathrm{L}(\boldsymbol{a}+\boldsymbol{a}) = \boldsymbol{2a\,L}$

$$\frac{\textbf{Volume of Cu for 3-wire system}}{\textbf{Volume of Cu for 2-wire system}} = \frac{3}{4}a\,L \times \frac{1}{2a\,L} = \frac{3}{8}$$

Hence a 3-wire system requires only 3/8th (or 37.5%) as much copper as a 2-wire system.

# Comparison of 3-phase 4-wire A.C. distribution and 2-wire D.C. distribution




$$I_{3\emptyset} = \frac{\sqrt{2}P}{3V\,cos^2\emptyset}$$

$$P_{loss} = 3I_{3\emptyset}^2 R_{3\emptyset} = 3\left(\frac{\sqrt{2}P}{3V\,cos\emptyset}\right)^2 R_{3\emptyset}$$

$$3\left(\frac{\sqrt{2}P}{3V\,cos\emptyset}\right)^2 R_{3\emptyset} = 2\left(\frac{P}{V}\right)^2 R_2$$

$$R_{3\emptyset} = (3cos^2\emptyset)R_2$$

neutral=outer

$$\text{Volume of Cu for 3-phase 4-wire system} = \frac{4}{3cos^2\emptyset}a\,L$$

$$\frac{\text{Volume of Cu for 3-phase 4-wire system}}{\text{Volume of Cu for 2-wire system}} = \frac{4}{3cos^2\emptyset}a\,L \times \frac{1}{2a\,L} = \frac{2}{3cos^2\emptyset}$$

# Comparison of A.C. and D.C. Transmission

The electric power can be transmitted either by means of d.c. or a.c. Each system has its own merits and demerits. It is, therefore, desirable to discuss the technical advantages and disadvantages of the two systems for transmission of electric power.

**1. D.C. transmission.** For some years past, the transmission of electric power by d.c. has been receiving the active consideration of engineers due to its numerous advantages.

**Advantages.** The high voltage d.c. transmission has the following advantages over high voltage a.c. transmission :

(*i*) It requires only two conductors as compared to three for a.c. transmission.

(*ii*) There is no inductance, capacitance, phase displacement and surge problems in d.c. transmission.

(*iii*) Due to the absence of inductance, the voltage drop in a d.c. transmission line is less than the a.c. line for the same load and sending end voltage. For this reason, a d.c. transmission line has better voltage regulation.

(*iv*) There is no skin effect in a d.c. system. Therefore, entire cross-section of the line conductor is utilised.

(*v*) For the same working voltage, the potential stress on the insulation is less in case of d.c. system than that in a.c. system. Therefore, a d.c. line requires less insulation.

(*vi*) A d.c. line has less corona loss and reduced interference with communication circuits.

(*vii*) The high voltage d.c. transmission is free from the dielectric losses, particularly in the case of cables.

(*viii*) In d.c. transmission, there are no stability problems and synchronising difficulties.

# Comparison of A.C. and D.C. Transmission

**Disadvantages**

(*i*) Electric power cannot be generated at high d.c. voltage due to commutation problems.

(*ii*) The d.c. voltage cannot be stepped up for transmission of power at high voltages.

(*iii*) The d.c. switches and circuit breakers have their own limitations.

**2. A.C. transmission.** Now-a-days, electrical energy is almost exclusively generated, transmitted and distributed in the form of a.c.

**Advantages**

(*i*) The power can be generated at high voltages.

(*ii*) The maintenance of a.c. sub-stations is easy and cheaper.

(*iii*) The a.c. voltage can be stepped up or stepped down by transformers with ease and efficiency. This permits to transmit power at high voltages and distribute it at safe potentials.

**Disadvantages**

(*i*) An a.c. line requires more copper than a d.c. line.

(*ii*) The construction of a.c. transmission line is more complicated than a d.c. transmission line.

(*iii*) Due to skin effect in the a.c. system, the effective resistance of the line is increased.

(*iv*) An a.c. line has capacitance. Therefore, there is a continuous loss of power due to charging current even when the line is open.